ONR Basic Research in Ocean Acoustics for FY03

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Grant Number: N00014-01-1-0217

LONG-TERM GOALS

The long-term goal of this research is to advance the knowledge base for low frequency sound propagation and scattering in complex shallow water environments. Specific goals include the discovery of the underlying physics for [1] the frequency dependence of complex sound speed in marine sediments and [2] reverberation due to marine sediments. A key challenge is to be able to ascertain these properties of the seabed from measurements that involve considerable coupling of the seabed acoustics to the properties of the water column whose properties often possess a significant degree of uncertainties in a specific experiment.

OBJECTIVES

There were four objectives of the research for FY03.

1. Complete the modeling of forward acoustic propagation data collected on a VLA during the East China Sea (ECS) component of the Asian Sea International Acoustics Experiment (ASIAEX).
2. Complete the analysis of extracting bottom scattering strengths from measured monostatic reverberation data taking during the ECS component of ASIAEX using the results of the analysis of the forward data.
3. Complete the development of a new physics based reverberation model that uses the Born approximation to explain the measured ASIAEX data.
4. Initiate a theoretical development of a 3-D reverberation approach based on the solution to the range and azimuth 2-way coupled mode equations.

APPROACH

1. The method of modeling the forward propagation data collected on a VLA during the ECS component of ASIAEX involves multiple steps. The first step is to identify several broadband events where the source spectra can be accurately identified. The method used in extracting a source spectrum without prior knowledge of the properties of the waveguide uses the fact that the shape of the source spectra characterizes the envelope of the magnitude of the received spectrum from an explosive source. In other words, the envelope of the source spectra is superimposed on the received spectra and that the effects of the propagation do not seriously alter this signature. The approximate recovery of a source spectrum for a specific event takes advantage of this observation by fitting a modeled source spectrum from an explosive source to the envelope of the received spectra. The reason that such an

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*
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1. REPORT DATE **30 SEP 2003**		2. REPORT TYPE			3. DATES COVERED **00-00-2003 to 00-00-2003**
4. TITLE AND SUBTITLE **ONR Basic Research in Ocean Acoustics for FY03**					5a. CONTRACT NUMBER
					5b. GRANT NUMBER
					5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)					5d. PROJECT NUMBER
					5e. TASK NUMBER
					5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Applied Research Laboratories,,The University of Texas at Austin,,P. O. Box 8029,,Austin,,TX,78758**					8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR'S ACRONYM(S)
					11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT **The long-term goal of this research is to advance the knowledge base for low frequency sound propagation and scattering in complex shallow water environments. Specific goals include the discovery of the underlying physics for [1] the frequency dependence of complex sound speed in marine sediments and [2] reverberation due to marine sediments. A key challenge is to be able to ascertain these properties of the seabed from measurements that involve considerable coupling of the seabed acoustics to the properties of the water column whose properties often possess a significant degree of uncertainties in a specific experiment.**					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

emphasis is placed on having a source spectrum is that the philosophy in this work is to model directly the received time series on the VLA over a large frequency band in order to infer characteristics of the seabed. A broadband normal mode approach in conjunction with a simulated annealing method is employed for this purpose. Each call of the inversion algorithm to the forward model multiplies the source spectrum by a simulated frequency response. Cost functions are based on correlations of measured and modeled spectra on the VLA. One method to estimate the surface properties of the seabed is to use long-range data at the higher frequencies, since these data effectively decouple the deeper from the surface properties of the seabed.

2. The method of extracting scattering strengths from reverberation data is centered on using a combination of both bistatic and monostatic data to uniquely determine the frequency dependence of the bottom scattering strength. This is accomplished by first doing an inversion analysis for the properties of the seabed employing [1] forward propagation data contained in data collected by P. Dahl and J. Miller on the APL:UW/URI VLA and [2] multi-frequency transmission loss data collected at a nearby location. The second step is to employ the knowledge of the properties of the seabed from the forward propagation inversion and analysis to construct a Green's function that accurately predicts the transmission loss. The analysis of the forward data allows one to compute an accurate transmission loss as a function of frequency which in turn allows for the extraction of the frequency dependent scattering strength from the monostatic reverberation data collected by the IOA. The uniqueness of the frequency dependence of the scattering strength is validated because the frequency dependence of the forward propagating Green's function (or TL) is known independently of the scattering data. This concept may be referred to as a decoupling approach (the effects of the background geoacoustics of the sediment are decoupled from the scattering parameters at the surface and within the volume of the seabed).

3. The development of a physics-based reverberation model is continuing in part through a collaboration with Dr. T. Yudichak, a post-doctoral researcher at ARL:UT. We have developed a normal mode based scattering model that assumes the validity of the Born or single scatter approximation. The approach is considered "physics based" in that the reverberation results from a scattering potential based on sound speed and density fluctuations within the seabed and on rough surfaces at the water-air interface, at the surface of the seabed, and at layer interfaces beneath the seabed. A statistical representation of the scattering potential in terms of power spectra is adopted that depends on such parameters as correlation lengths and standard deviations of the fluctuations, as well as power spectrum exponents.

4. The approach to develop advanced reverberation models that go beyond the Born approximation is to solve the full Helmholtz equation in 3-D. Surface roughness and fluctuations in the sound speed and density in the volume of the seabed create range and azimuth variations superimposed on a background waveguide. Both propagation and scattering are treated in a unified method by solving the full 3-D coupled mode equations. In this sense, there are no approximations to computing the scattered field, and the method allows one to systematically look at higher order corrections beyond the first Born term and to perturbatively separate the forward propagating from the scattered field.

The key individuals participating in this work include Dr. David Knobles and Dr. Thomas Yudichak at the Applied Research Laboratories, The University of Texas at Austin, and Dr. Peter Cable and Dr. Eugene Dorfman at BBN Technologies. Dr. Yudichak is supported in part by a post-doctoral fellowship provided by the Office of Naval Research. Dr. Peter Dahl from Applied Physics Laboratory, The University of Washington, and Dr. Jim Miller and Dr. Gopu Potty at the University of

Rhode Island provided the bistatic time series data received on the APL-UW/URI VLA for the purpose of inferring the geoacoustic structure of the seabed for the ECS location, and Dr. Rhene Zhang and his colleagues of the Institute of Ocean Acoustics (IOA), Beijing, China provided a monostatic reverberation time series measured on a quite day for the purpose of establishing bottom scattering strengths.

WORK COMPLETED

Work that was completed in FY03 include:

1. Most of the analysis of data selected on the APL-UW/URI VLA to aid in establishing the geoacoustic structure of the seabed has been completed. A manuscript is in preparation for the IEEE J. Oceanic Eng [2].
2. Using the results obtained in the forward propagation study, bottom scattering strengths as a function of frequency have been extracted from reverberation data supplied by the IOA. A manuscript is in preparation for the IEEE J. Oceanic Eng.[3]
3. A reverberation model that, uses (1) a normal mode approach to construct the free Green's function and (2) a wavenumber power spectra to represent bottom roughness and fluctuations of density and sound speed beneath the seabed, has been developed and tested. The model has been employed to generate preliminary reverberation time series to compare with the measured data taken by the IOA. A manuscript is in preparation for the J. Acoust. Soc. Am [4]
4. A new method that can separate the forward propagating field from the scattered or backward propagating field for non-separable problems in underwater acoustics has been developed. A manuscript has been submitted to a referred Proceedings of the 6th annual Conference on Theoretical and Computational Acoustics, 2003 [5].

RESULTS

1. Analysis of forward propagation data measured in ECS component of ASIAEX

The focus of the analysis of time series data collected on a VLA during the ECS component of ASIAEX was to determine the geoacoustic structure of the seabed[2]. It was found that the overall structure of the sound speed profile (SSP) in the water column and its uncertainty limited the degree of information about the seabed. While there were insufficient measurements of the SSP to determine the range-dependent nature of the waveguide for a specific event recorded on the VLA, there were enough measurements to demonstrate that the water column underwent significant dynamic changes during the broadband measurements. These fluctuations were perhaps a result of internal wave activity. To infer information about the surface properties of the seabed, long-range high frequency data were employed within simulated annealing calculations. Due to the time scale of the dynamics of the thermocline in the water column, it is necessary to make multiple simulated annealing calculations using the various measured SSP's in order to gain a quantitative measure of the uncertainty of the estimated properties of the seabed that results from the fluctuations within the water column.

Figure 1 shows a result of a single simulated annealing calculation using one of the measured SSP. The cost functions for all solutions tested in the course of the simulated annealing computation are saved, and then plotted as a function of specific parameters. Here the cost function is plotted as a function of the surface sound speed of the sediment. The observed minimum suggests a sound speed of about 1600 m/s. The corresponding data-model comparison of the received time series on the VLA

is shown in Fig. 2. Ongoing work is examining inversions for all the measured SSP's in order to quantify the uncertainty of the geoacoustic representation.

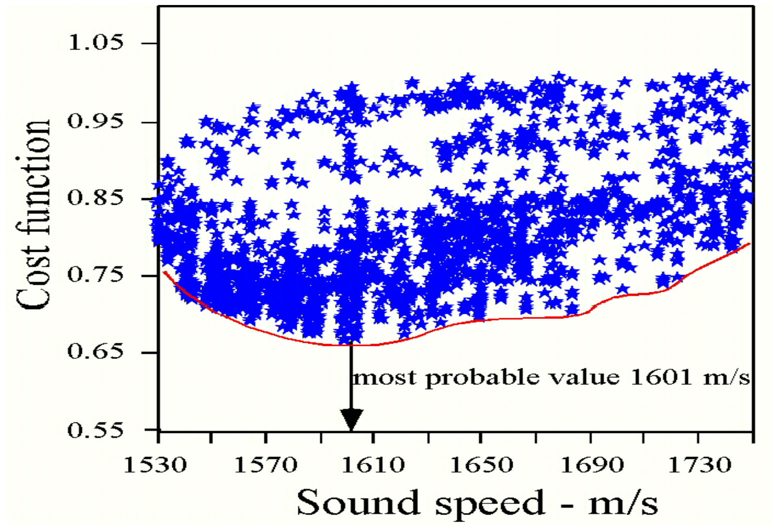

Figure 1: Cost function for surface sound speed of sediment.

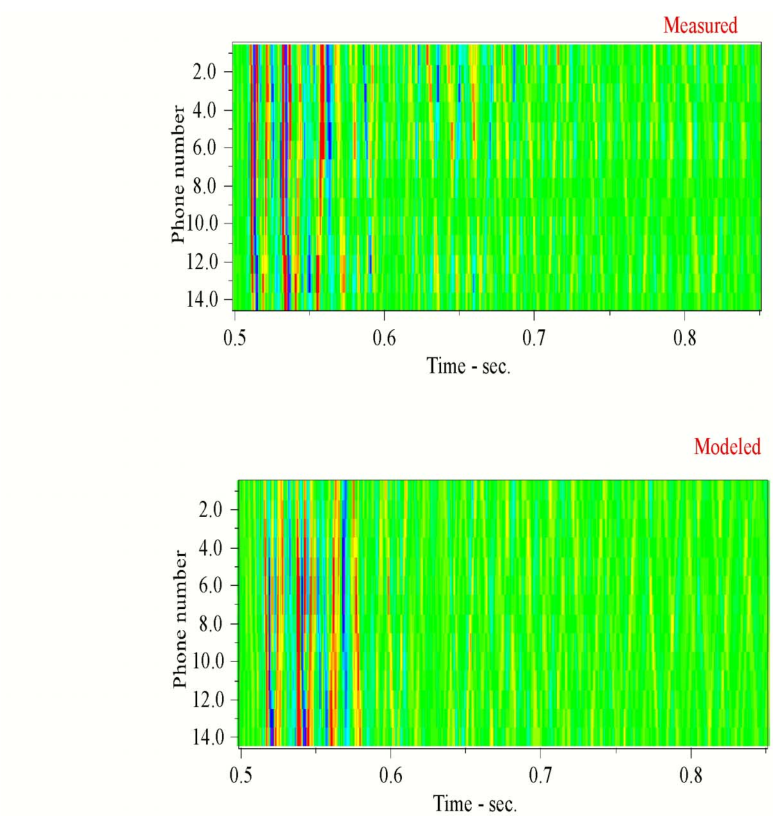

Figure 2: Comparison of modeled and measured time series on VLA in 50-350 Hz band using a geoacoustic profile obtained from inversion methodology.

2. Analysis of reverberation data measured in ECS component of ASIAEX

In a collaborative effort with P. Cable, Y. Dorfman, and T. Yudichak, an analysis was made for reverberation data collected during the East China Sea (ECS) component of ASIAEX [3]. Even though there is an issue of uncertainty with the geoacoustic structure, there is little uncertainty in using the correct transmission loss to extract bottom scattering strengths. It was found that the scattering strengths extracted from the ASIAEX data were in close agreement those extracted from a nearby Harsh Environment Project location. A variety of questions still remain on the physical mechanisms associated with the scattering strengths.

3. Physics based reverberation model

Using a geoacoustic profile obtained from an analysis of time series data collected on the APL-UW/URI VLA from small explosive sources and a measured SSP, the free Green's function propagator in a normal mode expansion was constructed. The volume spatial integral of the random fluctuations with the Green's function and its spatial derivatives were then evaluated numerically to compute the scattered field in a monostatic source-receiver geometry. Figure 3 shows a comparison of measured reverberation time series and those predicted by the reverberation model. The specific parameterization for the scattering potential only included a set of volume fluctuations within the seabed. The model and data time series are in 30 Hz band about the center frequencies of 100, 200, and 300 Hz.

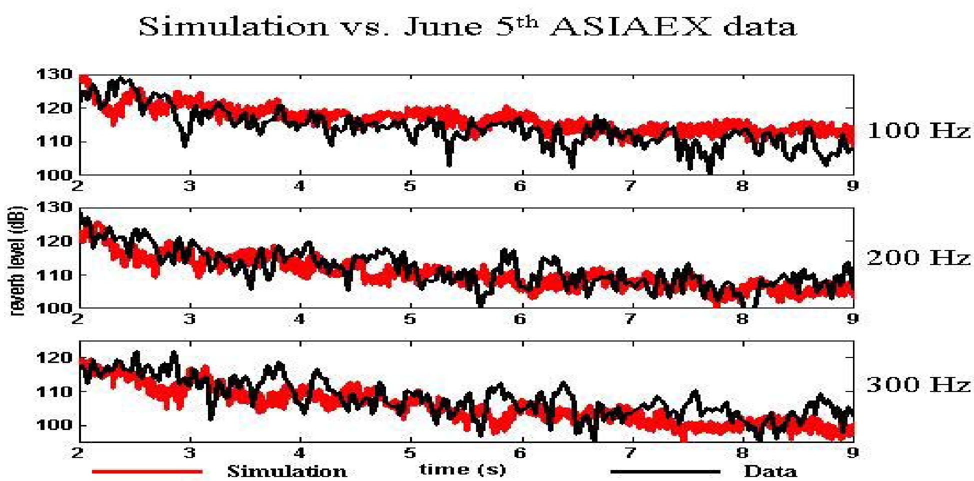

Figure 3: Comparison of modeled and measured reverberation time series taken in the ECS component of ASIAEX.

4. Two-way coupled mode approach with perturbative separation of scattered field

A separate approach was developed that goes beyond the Born approximation in that it attempts to solve the full 3-D scattering equations exactly, within the limits of finite differences and numerical integration. This approach uses previous work in solving two-way coupled mode equations in integral form. A new method has been introduced that separates the forward propagating and backscattered fields. The method is suitable even when the Born series for the scattering equations does not converge. Figure 4 shows the results of a calculation that separates the forward and backscattered fields. The pressure is presented in terms of transmission loss. Superimposed on Fig. 4 is the bathymetry of the waveguide. That has two hills. Figure 4a shows the total pressure field. It was found that the perturbation series for the effective interaction required only three terms for convergence . Figure 4b shows the result for the forward going acoustic field with no coupling to the backward propagating field. Clearly there are major differences between the total field and the forward propagating field since much of the structure in Fig. 4a results from the interference between forward and backward propagating components of the field. Figure 4c shows the result for the total pressure field where only one term is included from an expansion for the effective interaction between forward and backward propagating components. Although there are some differences with Fig. 4a, they are minor, indicating that the effect of backscattering is dominated by the first Born term in the effective interaction. Figure 4d shows the result for the forward component that has only a single correction term from the effective interaction. One observes that the difference between the forward scattered field without any corrections and the forward scattered field with the correction due to the backward scattered channels is small.

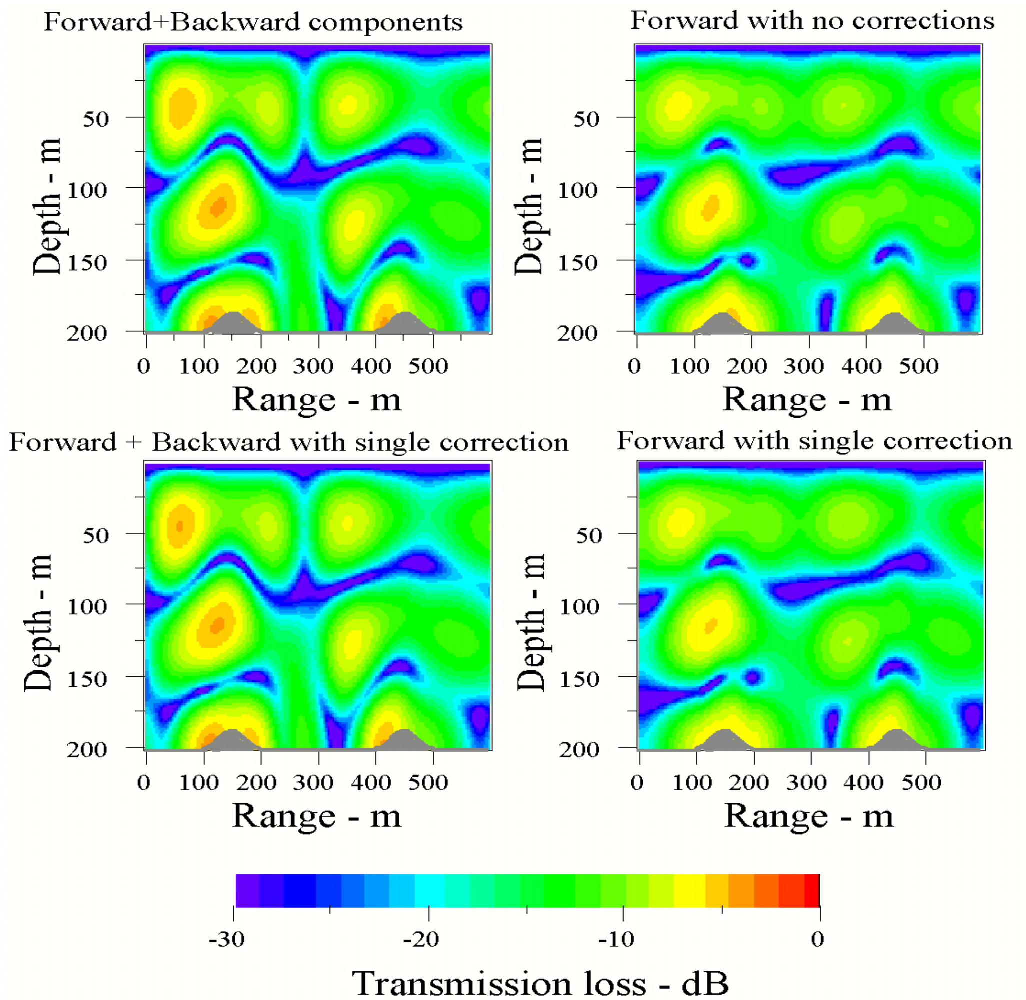

Figure 4: Magnitude of acoustic field in two-hill waveguide

IMPACT/APPLICATIONS

The potential impact of these studies includes the advancement of methodologies that can simultaneously infer the environment and localize sources of interest for both passive and active systems.

TRANSITIONS

A transition of this research is that the inversion algorithms constructed under this project have in part been used in other sponsored research, specifically SPAWAR PMW 150.

RELATED PROJECTS

A related project to the current research includes a 6.2 ONR project for University Navy Laboratories funded by Dr. John Tague, where the focus for the Applied Research Laboratories is to be able to localize sources and extract their source signatures in complex littoral multisource environments.

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PUBLICATIONS

1. D. P. Knobles, "A projection operator approach for non-separable and scattering problems in acoustics," submitted to the Sixth International Conference on Theoretical & Computational Acoustics, Honolulu, Hawaii, U.S.A, August 11-15, 2003. (refereed).

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